Apparatus and method of carrying out a melting and casting operation

Description

The invention concerns an apparatus for carrying out a melting and casting operation in the fine casting art, in particular the dental art, comprising a melting crucible for receiving melting charge, a heating device for heating the melting charge in the melting crucible and a pyrometer for ascertaining the temperature of the melting charge.

The invention further concerns a method of carrying out a melting and casting operation in the fine casting art, in particular the dental art, in particular with a casting apparatus of the above-specified kind, comprising the following steps: introducing melting charge into a melting crucible, heating the melting charge by means of a heating device and ascertaining the temperature of the melting charge by means of a pyrometer.

Casting apparatuses in the fine casting art of the kind set forth in the opening part of this specification are known, in which the temperature of the melting charge is measured by means of a pyrometer and, when a given temperature value is reached, an optical or acoustic signal is produced. The operator of the casting apparatus then recognises on the basis of that signal that he has to manually implement the impending casting operation.

The fine casting art, in particular the dental art, involves the manufacture of products, for example dental bridges, dental crowns and so forth, in regard to which the level of accuracy is a crucial consideration, more specifically within tolerances of smaller than 0.1 mm. The manufacture of such products involves casting a liquid metal alloy into a casting mold. By virtue of the high casting temperature of up to 2000°C as well as the impressions of teeth, which are produced at room temperature, and the patterns and casting molds which are to be produced therefrom, considerable temperature differences occur in the course of the procedure

for manufacturing such products. As moreover the materials used in the manufacturing process, for example the impression materials, wax patterns, casting molds and the product to be manufactured have very different properties, the differing coefficients of thermal expansion resulting therefrom can under some circumstances result in the above-indicated tolerances being exceeded. Therefore quite specific materials are selected whose differing coefficients of expansion substantially compensate each other.

However the temperature during the melting and casting operation also has a substantial influence on the level of accuracy and thus the aspect of observing the above-indicated tolerances. It is therefore important for such products to be cast under predefined, reproducible conditions.

Accordingly considerable significance is attributed to ascertaining the temperature involved during the melting and casting operation. For that purpose it must also be possible for the temperature to be exactly determined in a very wide range of between several 100 and about 2000°C. As already discussed hereinbefore so-called pyrometers are used for that purpose. These involve contactlessly measuring temperature measurement systems which detect infrared radiation emitted by the molten material or the melting charge and measure the radiation power. The measured radiation power however is highly dependent on the so-called emissivity which gives the ratio of the real emission value of a material and the emission value of the so-called (ideal) black-body radiator. The emissivity can therefore be at a maximum 1.0, that is to say the material in question corresponds to the ideal black-body radiator. The minimum emissivity in comparison is 0. Bodies whose emissivity is lower than 1 are referred to as gray-body radiators. Bodies whose emissivity is additionally dependent on temperature and wavelength are referred to as non-gray-body radiators. The materials used in the fine casting art are generally non-gray-body radiators of that kind. Added to that is the fact that the surface condition of the material alters when heating and melting metals or metal alloys. Even if the surface initially had a high shine or was polished, it will change substantially during the heating and melting procedure, in particular due to

oxidation or scaling. That causes the emissivity to be altered to a considerable degree.

The emissivity of metals and metal alloys as are frequently used in the fine casting art is therefore dependent in particular on the wavelength, the temperature and the material itself. Those dependencies are not taken into consideration or are only inadequately considered in known apparatuses and methods of carrying out melting and casting operations in the fine casting art. That leads to a reduction in the level of precision of the products to be manufactured.

Therefore the object of the present invention is to improve the quality of products manufactured in a melting and casting procedure.

In an apparatus of the kind set forth in the opening part of this specification the invention attains that object in that the apparatus additionally has a control device for controlling the melting and casting operation in dependence on the ascertained melting charge temperature, wherein the control device has a database with a plurality of selectable, respectively melting charge material-specific parameter sets each with one or more parameters for configuring the pyrometer.

In a corresponding manner in a method of the kind set forth in the opening part of this specification the invention attains that object in that the method controls a melting and casting operation in dependence on the ascertained melting charge temperature, wherein one of a plurality of melting charge material-specific parameter sets is selected from a database in dependence on the introduced melting charge and the pyrometer is configured by means of one or more parameters of the selected parameter set.

The invention therefore automatically matches the pyrometer being used to the properties of the respective melting charge being used, insofar as the appropriate configurational data for the pyrometer are read out of a database for each material or upon each change in material and the pyrometer is appropriately set. In that way the pyrometer is adapted to the respective different materials used. The temperature ascertained by means of the pyrometer can therefore be determined very exactly and thus the

melting and casting operation can be implemented under optimum conditions.

In addition the melting and casting operation is controlled in dependence on the ascertained melting charge temperature, that is to say automatically, and not manually. In that way the complete melting and casting operation can be carried out without intervention by the operator and thus independently of personnel. In that way the parameter sets stored in the database guarantee an optimum casting procedure in which the temperature of the molten material can be exactly detected at any time. The casting operation performed in that way is thus reproducible again and again.

In a preferred embodiment the pyrometer is a quotient pyrometer. A quotient pyrometer has two optical and electrical measurement channels. It is therefore also referred to as a dual-channel pyrometer. Each of the two channels measures in wavelength ranges which are different but which are as close together as possible and which in addition are of a narrow-band nature. That provides that the effects of material-specific particularities such as reflection or emission of the melting charge are approximately the same in relation to both wavelengths. A quotient formation operation in respect of the levels of radiation intensity measured by the two channels provides for eliminating certain measurement influences, in particular emissivity. Therefore, when using a dual-channel pyrometer, the negative influence of the varying emissivity can be substantially avoided. The use of a quotient pyrometer is therefore particularly advantageous.

In a further preferred embodiment each parameter set has one or more parameters for controlling the melting and casting operation in dependence on the melting charge material. In that way, the complete melting and casting operation is additionally also controlled by melting charge material-specific parameters, that is to say in dependence on the respective melting charge being used. Therefore - just like the pyrometer configuration - the melting and casting procedure is matched to the melting charge material used.

Further advantageous embodiments of the invention are set forth in the appendant claims and are apparent from the embodiments by way of example illustrated in the drawing in which:

Figure 1 is a simplified side view of a casting apparatus with a control device and a pyrometer in accordance with an embodiment of the invention, and

Figure 2 is a diagrammatic representation of the content of a database of the control device shown in Figure 1.

Figure 1 shows an apparatus 1 for carrying out a melting and casting operation in the fine casting art, as is used in particular in the dental art by dental laboratories. The apparatus has a melting crucible 2 for receiving melting charge (not shown) and a heating device 3 for heating the melting charge disposed in the melting crucible 2.

In the illustrated embodiment the heating device 2 is an induction furnace, by means of which in particular metal materials can be heated by induction. The invention however is not limited to induction furnaces of that nature. Alternatively for example there is provided a resistance-heated heating device. The heating device 3 is supplied with electrical power by a generator (not shown). The generator, that is to say the generator power output and thus also the heating power, is controlled by a control device 4.

Disposed beneath the melting crucible 2 and beneath the heating device 3 is a chamber 5 for accommodating a casting mold 6 into which liquid melting charge can be poured from the melting crucible 2, in order to produce for example dental bridges, dental crowns or other products in the fine casting art.

So that the melting charge can be transferred from the melting crucible 2 into the casting mold 6, the melting crucible in the illustrated embodiment is divided into two. One half, namely the right half in Figure 1, is adjustable in respect of height. By virtue of the melting crucible being vertically divided into two parts, a lifting movement of the right-hand half of the melting crucible 2 produces an opening in the lower region of the melting crucible so that the melting charge can pour into the casting mold 6.

For that purpose the right-hand half of the melting crucible 2 is mechanically coupled to an actuating device 7 which is capable of raising and lowering the right-hand half of the melting crucible 2. The actuating device 7 is also connected to the control device 4 so that the control device 4 can automatically initiate opening of the melting crucible and can thus start the pouring operation.

The invention however is not limited to two-part crucibles of that kind. Alternatively the pouring operation can also be implemented by a tilting movement of the melting crucible which is in one piece. However, a two-part melting crucible 2 is to be preferred as, with such a crucible configuration, the melting charge does not pass over the comparatively cold wall of the crucible before passing into the casting mold 6.

The chamber 5 is in the form of a pressure chamber. Prior to and during a casting operation that pressure chamber 5 is evacuated so that a vacuum obtains within the pressure chamber 5. Such a vacuum during the casting operation is advantageous as it prevents inclusions or air bubbles being formed within the product to be manufactured. After the melting charge has been passed into the casting mold 6 however an increased pressure is produced within the chamber 5 in order to press the melting charge into all regions of the casting mold 6. For that purpose the chamber 5 is connected to a reduced pressure/increased pressure pump (not shown) which is also electrically connected to the control device 4 so that the control device 4 can set the reduced pressure or increased pressure in the chamber 5.

During the entire casting process the respectively currently prevailing temperature of the melting charge is of particular interest. That temperature is measured in a contactless mode by means of a pyrometer 8. The pyrometer 8 has a sensor 9 which operates in the infrared range and which is connected to an optical system 11 by way of an optical waveguide 10. The sensor 9 is coupled by way of optoelectronic components to an electronic system 12 of the pyrometer 8 which converts optical signals or light signals into electrical signals, from which the radiation power detected by the sensor 9 can then be converted into a temperature value. In that

way it is possible for the sensitive sensor 9 and the sensitive electronic system 12 to be arranged far outside the region of the induction furnace 3 so that in that way electromagnetic incompatibilities can be effectively avoided.

The optical system 11 is disposed within a viewing window 13 which permits a view into the melting crucible 2. The viewing window 13 is designed to be pivoted upwardly so that it can be readily opened. The optical system 11 however is arranged at the viewing window 13 in such a way that, when the viewing window 13 is closed, the optical system is directed through the chamber window 13A at least on to a partial region of the melting crucible.

In alternative embodiments the optical system is disposed within a housing which fixedly encloses the interior of the apparatus 1 and which does not have a viewing window 13.

Alternatively the sensor 9 can be arranged directly without the interposition of an optical waveguide 10 in the immediate proximity of the melting crucible, for example in the region of the viewing window 13, in particular if the induction device is not an induction furnace which emits a high level of electromagnetic radiation, but for example a resistance-heated furnace.

The pyrometer is preferably a so-called quotient pyrometer (also referred to as a dual-channel, dual-color or ratio pyrometer). That quotient pyrometer has two optical and electrical measurement channels which are of substantially the same structure. The two measurement channels operate in two different wavelength ranges which however are of a very narrow-band nature and are closely adjacent to each other. That provides that the series of material-specific properties such as reflection and emission at the melting charge are substantially the same at both wavelengths. In that way, mathematical quotient formation makes it possible to eliminate various measurement influences such as for example emissivity so that the measurement procedure can be effected substantially independently of the actual level of emissivity.

The quotient pyrometer can be designed in various ways:

In a first variant division of the measurement radiation detected by the pyrometer is effected by means of two filters which are mounted rotatingly in front of the sensor. In that case measurement of the detected radiation is effected in the two channels in successive relationship in respect of time.

In a second variant division of the detected measurement radiation is effected by means of a beam splitter which passes the measurement radiation to two radiation detectors provided with different filters. That procedure also provides for the detection of two channels.

In a third variant the detected radiation passes without a beam splitter to a double sensor which has a filter and at which a front sensor simultaneously represents the filter for a second sensor arranged therebehind.

The temperature ascertained by means of the pyrometer 8 is passed to the control device 4 which controls or regulates the melting and casting operation in dependence on the ascertained temperature. The control unit has an input unit 14 for the input of melting charge identification or other input parameters and process variables. The control device 4 further has a display 15 in order to display inputted data or process data to the user.

The control device 4 further has a communication interface (not shown) for the input and output of data, in particular for supplementing and/or updating the data of a database associated with the control device 4, parameter sets, individual parameters and/or complex control programs and/or for reading out protocols and/or parameters of an implemented melting and casting operation.

Figure 2 shows the structure of such a database 16 associated with the control device 4. The database includes a plurality of individually selectable, melting charge material-specific parameter sets PS1, PS2, PS3 which each have a respective series of parameters P11, P12, P13, ...P21, P22, P23, ...P31, P32, P33,... . Each parameter set contains one or more parameters P1.., P2.., P3.. for configuration of the pyrometer 8. In addition each parameter set has one or more parameters P7.., P8.., P9.. for

controlling the melting and casting operation in dependence on the melting charge material being used.

In that way, associated with a specific melting charge material is a specific parameter set which on the one hand configures the pyrometer in dependence on the melting charge material properties and which on the other hand contains parameters, by means of which a melting and casting operation can be implemented in the optimum fashion and in particular reproducibly.

In a particular variant, for accurate configuration of the pyrometer and the melting and casting operation, material-specific items of information are divided up into material families or alloy families with substantially similar parameter sets.

The above-specified parameters involve on the one hand the following parameters which are used in particular for configuring the pyrometer but also for controlling the melting and casting operation: solidus temperature, liquidus temperature, emissivity ratio; information about the presence or absence of auxiliary devices in the region of the melting crucible such as for example graphite inserts which can influence pyrometer measurement.

In addition the procedure involves the following parameters which are used in particular for controlling the melting and casting operation: casting temperature; parameters relating to the operating procedure such as for example the magnitude of a reduction in the heating power when a given temperature is reached, for example the liquidus temperature; the period of time for which the casting temperature is held constant until a casting operation is initiated; base values in respect of predefined heating curves which specify the heating output power to be set in dependence on temperature; parameters relating to the procedure in respect of time of the casting operation as from initiation of the casting operation under a reduced pressure or vacuum until the moment of producing an increased pressure or a pressing pressure; and the values of the vacuum pressure and the increased pressure.

The illustrated casting apparatus 1 can be operated in a number of different modes of operation by means of the control device 4:

In a first mode of operation a user, on the basis of an identification or reference number which is to be inputted and by means of which in particular a given alloy is identified, can select a melting and casting program which is fixedly stored in the control device or a melting and casting program which is read from an external data carrier, the melting and casting process being individually controlled by means of the selected program.

In a second mode of operation the user can himself input his own melting and casting programs and store them in the control device 4 or in the database 16. That mode of operation is relevant in particular if the user processes alloys from other manufacturers or alloys which the user himself has produced.

In a third mode of operation the user inputs manual process parameters such as generator power, the vacuum during the casting process and the casting temperature in order in that way to implement an individual melting and casting operation.

In a fourth mode of operation the control is switched into a so-called learning mode, in which the control itself recognises and records the solidus-liquidus curve of a given alloy.

The various modes of operation can be selected by way of the input unit 14.

A preferred procedure for the melting and casting operation is described hereinafter.

A user firstly selects a melting charge to be processed and introduces it into the melting crucible 2. At the same time or shortly therebefore or shortly thereafter the user, by way of the input unit 14, inputs an identification or a reference number by way of the input unit 14, and that is then processed by the control device 4. On the basis of that identification, the control device 4 selects from a database one of a plurality of parameter sets, more specifically that which is associated with the corresponding identification. On the basis of one or some of the parameters of the

selected parameter set, the control device configures the pyrometer 8 and more specifically in particular the electronic system 12 thereof. By virtue of that configuring procedure, temperature measurement by means of the pyrometer 8 can be adapted exactly to the particular properties of the melting charge being used.

The pyrometer then continuously ascertains the temperature of the melting charge which has been introduced into the melting crucible 2. At the same time the control device 4 controls the heating device 3, for example the induction current of an induction furnace, which flows through an induction coil. That causes heating of the melting charge which is heated by the induction effect. The heating procedure is continuously controlled by the pyrometer. The heating operation and in particular the heating power of the heating device 3, for example the induction current, is controlled and therewith also the entire melting and casting operation in dependence on the melting charge temperature ascertained by the pyrometer 8.

The selected parameter set also includes further parameters relating to the melting and casting operation. In that way the melting and casting operation is adapted to the particular properties of the melting charge being used.

During that operation, the molten material is kept substantially constant for a predetermined period of time when a predetermined temperature is reached. When that or another predetermined temperature of the molten material is reached, the heating power of the heating device is reduced. In that way the melting charge being used is heated to the casting temperature in a particularly careful and gentle fashion.

In a particularly advantageous embodiment the control device 4, on the basis of the melting charge temperature variation which is ascertained during the melting operation, in particular the ascertained solidus temperature and/or the ascertained liquidus temperature, determines which melting charge is involved and then selects the parameter set associated with that melting charge automatically, that is to say without an input of the identification of the melting charge on the part of the operator.

It is possible in that way to completely exclude incorrect operations, so that the reliability of the melting and casting apparatus 1 is enhanced.

In a further embodiment, as illustrated in Figure 1 by a broken line, an auxiliary means for promoting the heating operation, for example a tubular graphite insert 17, is disposed within the melting crucible 2 or in the region of the melting crucible 2. The graphite insert 17 is heated by currents induced in the graphite insert 17 and in that case is caused to glow. When that happens, residual oxygen present within the melting chamber - enclosing the melting crucible 2 - burns to form carbon dioxide. That prevents oxidation of the molten material as a protective gas is formed.

A further advantage of the graphite insert 17 is that the molten material is gently and carefully caused to melt as the melting charge is heated primarily by the thermal radiation emanating from the graphite insert 17 and only in part by direct induction caused by the induction coil of the induction furnace. The consequence of this is that the visual melting image is improved as the molten material is caused to move to a lesser degree due to magnetic fields.

The graphite insert 17 however has a very high level of emissivity. In addition it also heats up more quickly than the melting charge. Therefore the pyrometer 8 also detects thermal radiation emanating from the graphite insert and thus measures a superimposed temperature in respect of the graphite insert 17 and the melting charge.

However, after a period of time t_V substantial temperature equalisation occurs between the graphite insert 17 and the molten material. That period of time t_V is proportionally shorter, the higher the temperature of the graphite insert 17. The cause of this is better heat transfer due to thermal radiation at higher temperatures, which depends on the fourth power of the temperature. At high temperatures T_o in the range of between 1300°C and 1600°C, for example around 1400°C, the period of time t_V becomes substantially zero.

In comparison at lower temperatures T_u, in the range of between 800°C and 1100°C, for example 1000°C, a temperature difference $T_{\ddot{U}}$ =

$T_{const.}$ remains between the graphite insert 17 and the melting charge, wherein $T_{const.}$ is in the range of between 50°C and 250°C, in particular between 80°C and 180°C, or $T_{const.}$ is substantially 100°C. That temperature difference $T_{Ü}$ however also becomes substantially zero at the above-indicated high temperatures T_o in the range of between 1300°C and 1600°C, for example around 1400°C.

A preferred embodiment therefore provides for compensation of the above-described effects, by a procedure whereby, when a graphite insert 17 is present, the ascertained melting charge temperature is reduced by the temperature difference value $T_{Ü}$, more specifically in particular in accordance with the following approximation equation in which T_G denotes the casting temperature, T_o denotes an upper, empirically ascertained temperature value in the above-indicated range, T_u is a lower, empirically ascertained temperature value in the above-indicated range and $T_{const.}$ is an also empirically ascertained temperature constant in the above-indicated range:

$$T_{Ü} = ((T_o - T_G)/(T_o - T_u)) * T_{const.}$$

The following applies for a preferred embodiment:

$$T_{Ü} = ((1400°C - T_G)/(1400°C - 1000°C)) * 100°C$$

In addition a given moment in time, for example the moment in time of casting, when a graphite insert 17 is involved, is displaced by the period of time t_V, that is to say, there is a delay for that period of time t_V before the casting operation is initiated. At the above-indicated low temperatures T_u that period of time t_V assumes a value $t_{const.}$ in the range of between 10 and 120 seconds and in particular is substantially 60 seconds while at higher temperatures T_o it becomes substantially zero. The period of time t_V is preferably determined in accordance with the following equation, wherein T_o, T_u, T_G and $t_{const.}$ are in the above-indicated ranges of values:

$$t_V = ((T_o - T_G)/(T_o - T_u)) * t_{const.}$$

The following applies for a preferred embodiment:

$$t_V = ((1400°C - T_G)/(1400°C - 1000°C)) * 60sec$$

As those formulae furnish only a linearly approximated result, a further configuration of the invention involves the provision of a polynomial of n-th degree for accurate calculation of the values for $T_Ü$ and t_V.

In detail therefore the melting and casting operation will preferably take place as follows:

After the melting charge has been raised in accordance with the above-described method to the casting temperature, having regard to the above-specified temperature difference $T_Ü$, the procedure waits for a period of time t_V in accordance with the above-indicated approximation equation.

Then, while the supply of power to the heating device 3 is switched off, a casting mold 6 which has been preheated to between about 700 and 1050°C is introduced into the chamber 5. The period of time for which the supply of power is switched off is of the order of magnitude of 10 sec.

The chamber 5 is then evacuated, that is to say a vacuum is produced. The molten material is now heated again to the intended casting temperature, more specifically again having regard to the above-indicated temperature difference $T_Ü$. The procedure then waits for a period of about 1/3 t_V and then the casting operation is initiated.

As described, the graphite insert 17 has a considerable influence on temperature measurement. In a particular embodiment therefore, in dependence on the presence or absence of such a graphite insert 17, a respective other parameter set is selected or a parameter set contains a suitable parameter which denotes the presence or the absence of such a graphite insert 17 in order then within the control device 4 to implement suitable compensation in respect of the above-discussed effects which are related to the graphite insert 17, more specifically in accordance with the above-indicated equations.

The presence or absence of a graphite insert can be notified by manual input by way of the input unit 14 of the control device. Alternatively the arrangement has a detector for recognising an auxiliary means of that kind. This involves either a contact sensor or a weight sensor which is in relationship with the crucible 2. The presence of a graphite insert can however also be ascertained from the electrical parameters of the induction

furnace as they are influenced by the introduction of a graphite insert. Each of those detectors is connected to the control device 4 so that it can automatically implement the above-described compensation actions.

In a further embodiment the control device 4 has a pyrometer calibration mode in which the control device 4 sets calibration parameters for calibrating the pyrometer 8 in dependence on a temperature pattern ascertained with a given reference melting charge, in particular the solidus-liquidus characteristic. For that purpose, a reference melting charge, preferably a pure metal such as pure copper, is introduced into the melting crucible 2 and a melting operation is performed. During the melting operation the pyrometer 8 ascertains the temperature variation and compares that temperature variation to a reference characteristic stored in the database 16, in particular the solidus-liquidus reference characteristic of the reference melting charge used. The pyrometer 8 is checked and possibly calibrated on the basis of the comparative result.

By virtue of the invention, temperature measurement during a melting and casting operation in the fine casting art can be performed to a substantially higher level of accuracy and thus the casting operation can be carried out exactly and reproducibly again and again. Automatic configuring of the pyrometer and the melting and casting operation very substantially eliminates human error in operation. Therefore, by virtue of the invention, the proportion of defective products can be considerably reduced and thus the item costs can be lowered.